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AN OPTICAL DEVICE FOR MEASURING REFRACTIVE-INDEX FLUCTUATION IN--ETC(U)

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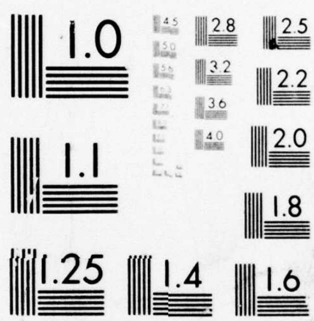

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
ECOM 77-9

AN OPTICAL DEVICE FOR MEASURING REFRACTIVE-INDEX FLUCTUATION IN THE ATMOSPHERE

By

G. R. Ochs
R. F. Quintana
G. F. Miller

For

Atmospheric Sciences Laboratory
U.S. Army Electronics Command
White Sands Missile Range, New Mexico 88002

October 1977

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UNITED STATES ARMY ELECTRONICS COMMAND - FORT MONMOUTH, NEW JERSEY

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AN OPTICAL DEVICE FOR MEASURING REFRACTIVE-INDEX FLUCTUATION IN THE ATMOSPHERE

G. R. Ochs, R. F. Quintana and G. F. Miller

An instrument is described that measures the average value of the refractive-index structure constant (C_n^2) over optical paths from 80 to 800 meters. Corrections for the inner scale of turbulence and difficulties due to the saturation of scintillation, both present in previous optical techniques, are avoided by using an extended incoherent light source.

1. INTRODUCTION

A recent paper (Wang, et al., 1978) describes a new optical technique for measuring the refractive-index structure parameter C_n^2. Through the use of an extended incoherent transmitter and large receiving optics, the technique requires no corrections for the inner scale of turbulence and avoids problems arising from the saturation of scintillation, which may occur on optical paths having high integrated refractive-index turbulence. An instrument designed and built on this principle is described in this report. It measures C_n^2 over the range 10^{-12} to 10^{-16} $M^{-2/3}$ on optical paths from 80 to 800 meters.

2. DESCRIPTION OF THE INSTRUMENT

The light source and receiver are shown in Fig. 1. The light source uses a quartz-iodine 20 W bulb operated at 11 volts DC from a regulated power supply. The light is at the focus of a 5-cm diameter objective, but to insure uniform illumination of the objective a fine ground glass is placed in front of the bulb. This also enlarges the projected light beam to reduce sensitivity to movement of the mount.

The receiver optics consist of a 20 x 50 binocular with photodiodes mounted in the plane of the exit pupils. All of the light at the exit pupil (2.5 mm dia) is taken in by the 5-mm diameter photodiode. With this arrangement, the instrument will have uniform response to light over a 3° field of view, so that some movement of the receiver mount can be tolerated. Angular movement of the receiver in the daytime will, however, result in undesirable fluctuations in background light received in the 3° field of view. These fluctuations are minimized by taking the difference of the signals received by the two objectives. Since the fields of view of the two optical systems coincide, background fluctuations will largely be nulled

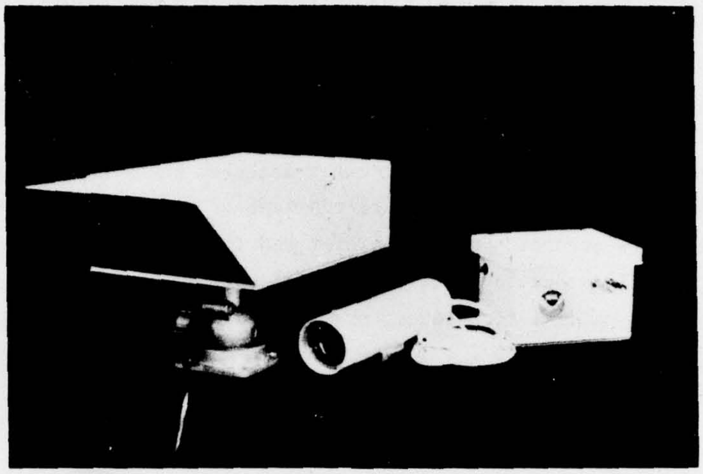


Figure 1. C_n^2 *meter light source and receiver.*

out. The two objectives are far enough apart so that the scintillation is uncorrelated and the signal power is doubled.

Smaller values of C_n^2 can be measured when the light source and receiver are mounted on a solid, vibration-free mount. The performance obtained with optically solid mounts can be improved even more by inserting a smaller field stop in the binocular. For example, cutting the field of view from 3° to 0.3° will reduce the background by a factor of 100, resulting in a very significant noise reduction in daylight.

The receiver electronics provide a convenient way to measure the fractional scintillation (RMS signal fluctuation/mean signal strength), which is directly proportional to $\sqrt{C_n^2}$ within the limits described later. The circuit consists of a difference amplifier of adjustable gain, a bandpass filter, and an RMS module. For calibration purposes, a switch (a BNC connector is provided for remote operation) disconnects one photodiode, bypasses the highpass filter, and reduces the gain by a factor of 10. Both linear and logarithmic signal outputs are available.

3. OPERATING PROCEDURE

One person can align the light source by placing a corner reflector at the receiver location. Slow angular movements of the receiver mount within the 3° receiver field of view should not affect the operation. The system is also relatively insensitive to a similar angular movement of the light source. Nevertheless for minimum noise the light source and receiver should be mounted as solidly as possible.

The instrument is calibrated at night to obtain accurate DC light levels. The procedure is as follows. Set the calibrate switch to CAL and observe the difference in voltage at the linear output ($\bar{V}_m$) when the light source is turned on and off. Note that in the CAL position there is a small positive DC offset with zero signal in (light off). This prevents errors in measuring $\bar{V}_m$ that would result from a negative offset being rectified in the RMS circuit, causing an error in the difference voltage. Pot C should be adjusted for $\bar{V}_m$ approximately equal to that shown in the graph of Fig. 2, for best signal-to-noise and largest dynamic range. To avoid saturating the electronics, $\bar{V}_m$ should not exceed 10 volts. The refractive-index structure constant (C_n^2) is then (see Appendix B)

$$C_n^2 = 5.16 \times 10^{-6} \frac{V^2}{L^3 \bar{V}_m^2} \tag{4}$$

where V = linear output voltage,
$\bar{V}_m$ = difference voltage,
L = path length, meters.

After the initial setup, the calibration can be checked by using the remote calibration switch. Place the switch in CAL at night and turn the light source on and off to measure $\bar{V}_m$. If $\bar{V}_m$ has changed slightly, the calibration can be adjusted according to equation (4).

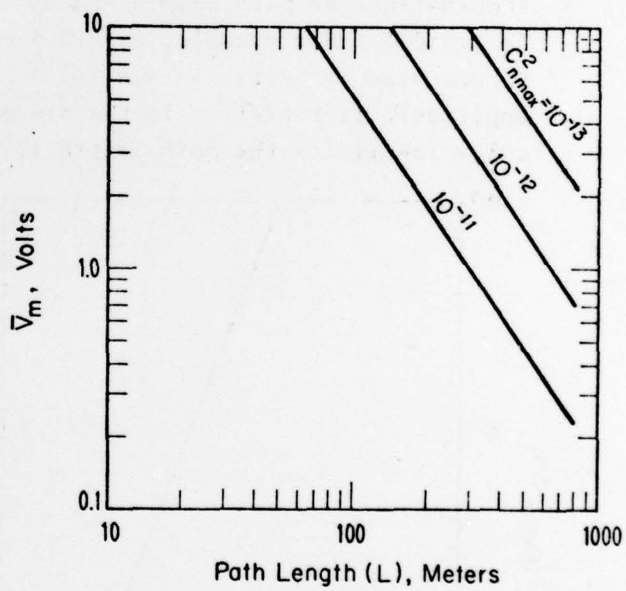


Figure 2. $\bar{V}_m$ vs path length and full scale C_n^2.

Equation (4) may be calculated in a computer, if desired, by digitizing the signal BNC output. Sampling rates as slow as one per second may be employed, as long as the sampling interval is less than 1 msec. A digital high-pass filter can be employed (cutoff ≈ .01 Hz) to remove any possibility of DC offsets. While a lot of information is lost with one-second sampling rates, it is usually not important when C_n^2 is averaged over intervals of one minute or more. A more serious consideration is the prevention of AC noise pickup on the signal lead from the instrument to the computer digitizer.

In practice, the log output (E) may prove to be the best choice when long signal cables are required. To use this output, set the gain (pot C) in the same way as before. Then switch to the log output, set the calibrate switch to CAL, and observe the difference in voltage at the log output with the light on ($\bar{E}_{on}$) and off ($\bar{E}_{off}$). Then (see Appendix B),

$$C_n^2 = 5.16 \times 10^{-6} \frac{10^{E}}{L^3 (10^{\bar{E}on/2} - {}^{\bar{E}off/2})^2} \tag{5}$$

Again, the remote calibration switch can be used to check the calibration, and small differences can be corrected by the use of equation (5). To obtain correct mean C_n^2 values, equation (5) should be performed before any averaging takes place, i.e., average C_n^2, not $\log(C_n)$.

The saturation of scintillation determines the upper limits imposed on the optical path length and full scale C_n^2 reading, and the relationships are shown in Appendix B. Equation (8) of Appendix B is plotted in Figure 3. Combinations of path length and C_n^2 values to the right of the line should be avoided. For example, on a 500-m path, the maximum value of C_n^2 that can be measured correctly is 4×10^{-12}. In addition, the calibration equations apply only if $D > 2\sqrt{\lambda L}$. In the present instrument, for $\lambda = 0.8 \times 10^{-6}$M, this criterian limits the path length to 800 M regardless of C_n^2.

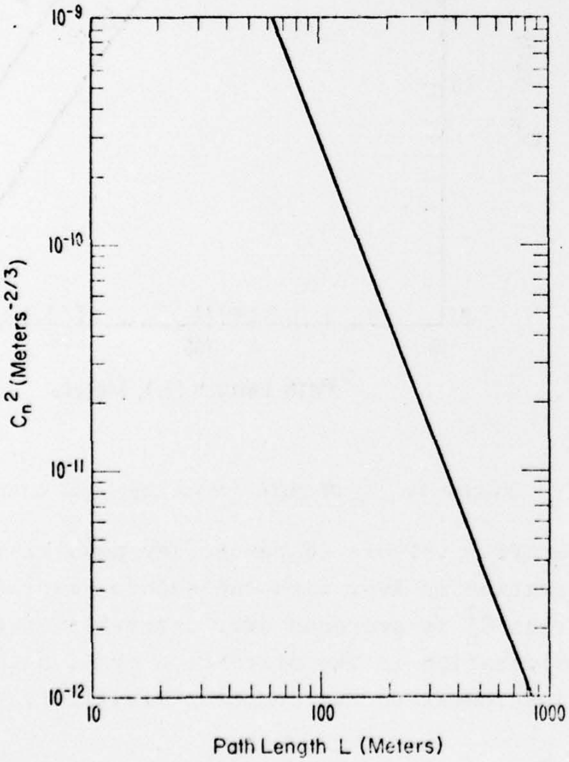


Figure 3. Path and C_n^2 upper limits imposed by the saturation of scintillation.

4. ALIGNMENT PROCEDURE

1. Ground pins 2 and 3 of op amp 3 and set it to zero at pin 6 by adjusting pot B.

2. Point the receiver at a small AC light at least 10 meters away. With the calibrate switch in the run position, adjust pot A for minimum AC at the signal BNC.

3. With op amp 7 removed, inject +0.10 volts DC at the signal BNC, and adjust F for 0.00 volts at log output BNC.

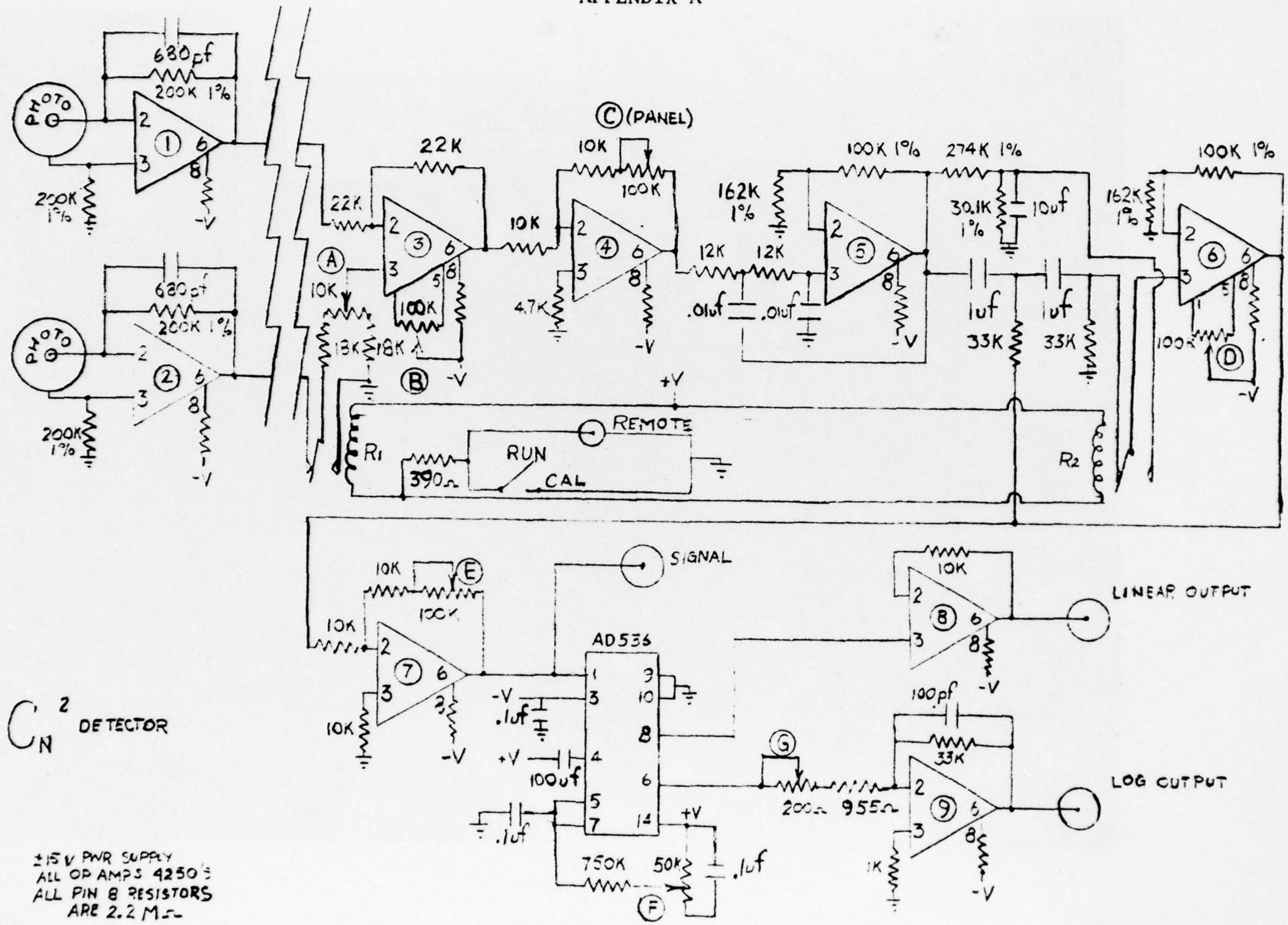
4. Inject +1.00 volts DC at the signal BNC and adjust G for +2.00 volts at the log output BNC.

5. Disconnect DC voltage from the signal BNC and replace op amp 7. Remove op amp 3 and ground socket pin 6. Set pot E for maximum gain (CCW) and the calibrate switch to RUN. Then adjust D for minimum voltage (should be within 10 mV of zero) at the linear output BNC. This should coincide with zero volts at the signal BNC.

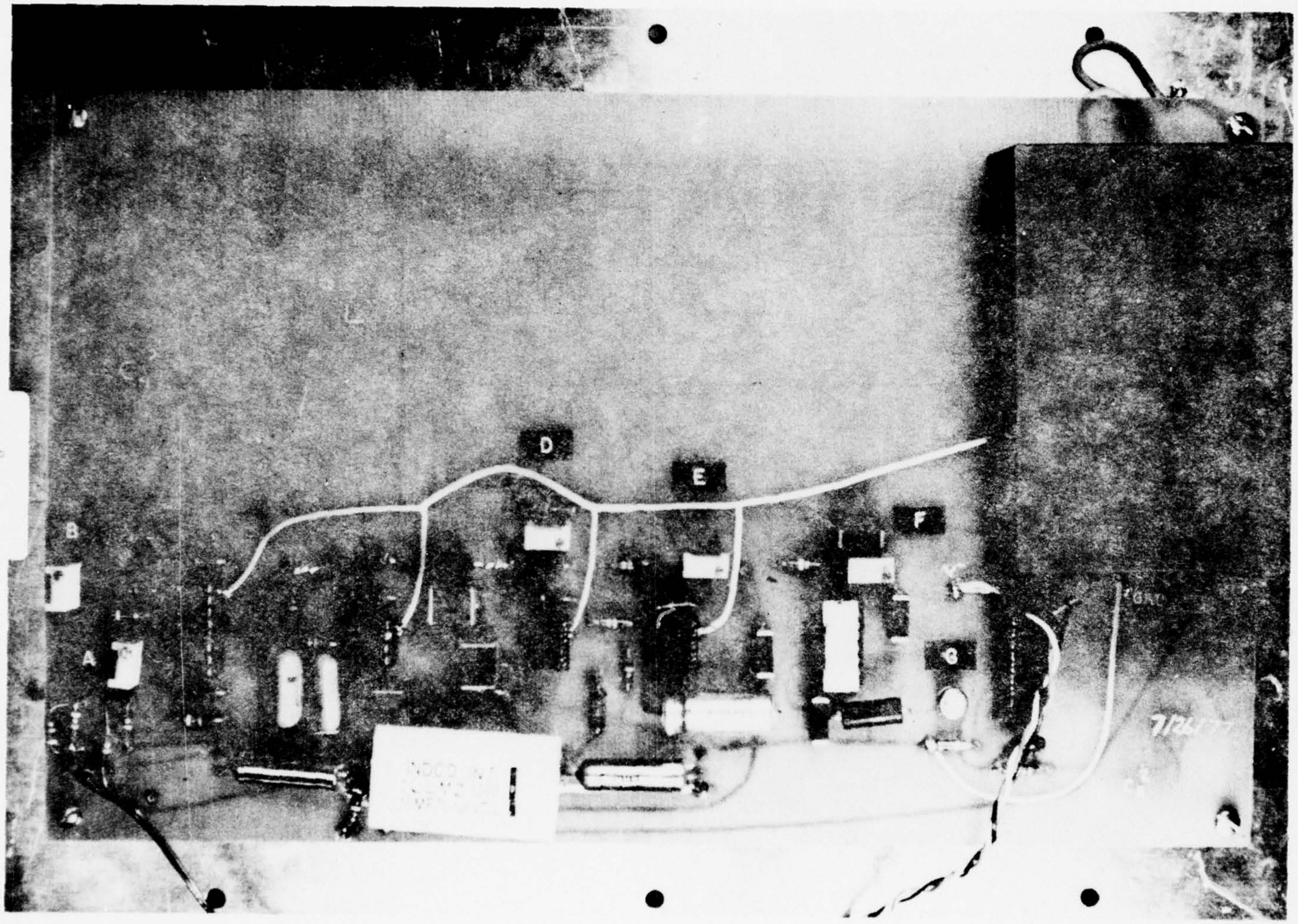
5. REFERENCE

1. T-i Wang, G. R. Ochs and S. F. Clifford, A Saturation-resistant Optical Scintillometer to Measure C_n^2 (Accepted for publication, J. Opt. Soc. Am., tentative issue March 1978).

APPENDIX A



CIRCUIT DIAGRAM



CIRCUIT BOARD

APPENDIX B

C_n^2 Calibration

From reference 1, for one aperture,

$$C_n^2 = 4.48\ \sigma_\chi^2\ D^{7/3}L^{-3} \tag{1}$$

where σ_χ^2 is the log-amplitude variance of the irradiance. For $\sigma_\chi^2 << 1$, the above can be written in terms of light intensity I as

$$C_n^2 = 1.12\ \frac{<(I-\bar{I})^2>}{\bar{I}^2}\ D^{7/3}L^{-3}\ . \tag{2}$$

In the instrument, we observe light intensity I_a in one aperture and I_b in another aperture, sufficiently separated from the first so that the intensity fluctuations are uncorrelated. In addition, the calibration procedure sets $I_a=I_b$, and measures I_a and $<(I_a-I_b)^2>$. So rewriting (2) in terms of measured instrument quantities we have

$$C_n^2 = \frac{1.12\ <(I_a-\bar{I}_a-I_b+\bar{I}_b)^2>\ D^{7/3}L^{-3}}{2\bar{I}_a^2}$$

$$= \frac{0.560\ <(I_a-I_b)^2>\ D^{7/3}L^{-3}}{\bar{I}_a^2}\ .$$

In terms of voltage at the linear output and for D=.050 M,

$$\begin{aligned} C_n^2 &= 0.560 \times .050^{7/3}L^{-3}\bar{V}^{-2}V^2 \\ &= 5.16 \times 10^{-4}L^{-3}\bar{V}^{-2}V^2\ . \end{aligned} \tag{3}$$

In the instrument a gain change is made in the CAL position so that the measured DC voltage

$$\bar{V}_m = 0.1\bar{V}.$$

Then (3) becomes

$$C_n^2 = 5.16 \times 10^{-6} \frac{V^2}{L^3 \bar{V}_m^{\,2}} \qquad (4)$$

The log output (E) is set for 2 volts/decade and 0 volts out for 0.1 volt in, so that $E = 2 \log_{10}(10V)$ or $V = 10^{E/2}/10$. Also $\bar{V}_m = (10^{E_{on}/2} - 10^{E_{off}/2})/10$. In terms of the log output, (4) becomes

$$C_n^2 = 5.16 \times 10^{-6} \frac{10^E}{L^3 (10^{E_{on}/2} - 10^{E_{off}/2})^2} . \qquad (5)$$

SATURATION CRITERIA

Assume $C_n^2 = 10^{-12}$ maximum. From reference 1, the transmitter and receiver diameters required to prevent saturation effects are

$$\alpha_r + \alpha_t > 1.95 \, (\sigma_T^2)^{3/4} \qquad (6)$$

where α_r = receiver diameter in Fresnel zones,

α_t = transmitter diameter in Fresnel zones, and

$\sigma_T^2 = 0.124 \, (\frac{2\pi}{\lambda})^{7/6} L^{11/6} C_n^2$ (λ = light wavelength).

Letting $\alpha_r = \alpha_t = D/\sqrt{\lambda L}$, (6) becomes

$$\frac{2D}{\lambda^{1/2} L^{1/2}} > 1.95 \, [0.124 \, (\frac{2\pi}{\lambda})^{7/6} L^{11/6} C_n^2]^{3/5} . \qquad (7)$$

In terms of aperture diameter,

$$D > \lambda^{-1/5} L^{8/5} (C_n^2)^{3/5} . \qquad (8)$$

In terms of path length,

$$L < D^{5/8} \, \lambda^{1/8} (C_n^2)^{-3/8} . \qquad (9)$$